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UNITED STATES DEPARTMENT OF AGRICULTURE

BULLETIN No. 508

Contribution from the Forest Service
HENRY S. GRAVES, Forester

Washington, D. C. PROFESSIONAL PAPER March 6, 1917

YIELDS FROM THE DESTRUCTIVE DISTILLATION OF CERTAIN HARDWOODS.

SECOND PROGRESS REPORT.

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PURPOSE OF EXPERIMENTS.

The object of the investigations reported in this bulletin and in Bulletin 129, to which this is supplementary, was to determine the relative value of the various hardwoods commonly used for destructive distillation, and of the different forms of material, such as bodywood, limbs, and slabs. The experiments were carried on at the Forest Products Laboratory, maintained at Madison, Wis., in cooperation with the University of Wisconsin. The standard species—beech, birch, and hard maple—were included in the laboratory tests so as to make the results on other species comparable with them and hence commercially applicable. Bulletin 129 gives the yields for these three standard species, and, in addition, red gum, chestnut, hickory, white oak, and tupelo. The present bulletin gives the yields for white elm, slippery elm, silver maple, green ash, blue ash, yellow ash, chestnut oak, tanbark oak, California black oak, Louisiana swamp oak,[1] and eucalyptus.

The results here reported are of most value when compared with laboratory distillations of species whose yields in commercial prac-

[1] "Swamp oak" was a mixture of laurel, post, water, willow, Spanish, and cow oaks, usually growing in mixed stands. Acknowledgment is made of the assistance of Mr. H. Cloukey in analyzing some of the distillates.

NOTE.—This bulletin gives the results of experiments in destructive distillation of hardwoods and is of interest to manufacturers of by-products.

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tice are well known. Laboratory methods of distilling are not comparable directly with commercial conditions, and the calculated yields per cord from laboratory distillations on 100 or 200 pounds of material are frequently much higher than the yields from distilling several thousand pounds in the commercial plant.

PLAN OF INVESTIGATION.

The apparatus used and the manner of making the tests are described in Bulletin 129. Both body and slab wood were distilled in most cases and in a few species limb wood was included in the study.

The yields of wood alcohol and acetic acid were determined by analysis of the pyroligneous-acid liquor,[1] and the amount of tar and charcoal was determined by measurement. The average was taken of three or four tests on each form of material.

METHOD OF RECORDING DATA.

The yields are expressed in three ways: (1) As a proportion of the oven-dry weight of the wood distilled (it is only on this basis that the results are independent of varying percentages of moisture in the material and of differences in the weight of unit volumes); (2) in the commercial units, gallons of 82 per cent crude wood alcohol and pounds of 80 per cent gray acetate of lime per cord of air-dry wood;[2] and (3) as a proportion of the yield of a cord of equal parts of beech, birch, and maple.

YIELDS ON PERCENTAGE WEIGHT BASIS, ALCOHOL AND ACETIC ACID.

VARIATION AMONG SPECIES.

The average yields of acetic acid and wood alcohol expressed in percentages based on the oven-dry weight of the material distilled are given in Table 1. The yields from a previous study of the standard species, beech, birch, and maple, are given for comparison. On this basis several of the species tested compare very favorably with the standard species. White elm, slippery elm, silver maple, and black ash gave nearly the same yields of alcohol as beech and hard maple. The acetic-acid yield of white elm, silver maple (heartwood), tanbark oak, and California black oak (limbs) were very nearly the same as that of birch, and considerably larger than the yield of beech and maple.

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[1] The methods of analysis are given in Klar's Technologie der Holzverkohlung, p. 337, except that in the alcohol analysis a final distillation is made after adding a few cubic centimeters of concentrated H_2SO_4 to eliminate the wood-oil constituents.

[2] A cord of air-dry wood is assumed for purposes of comparison to be equal to 90 cubic feet of solid wood containing 15 per cent moisture (calculated on the dry weight). The weights per cubic foot of wood are those given in "The Principal Species of Wood," by C. H. Snow. Recent investigations by the Forest Service show weights per cubic foot slightly different from those used in these calculations, but the relative values are not changed.

TABLE 1.—*Yields of alcohol and acetic acid in percentages based on the oven-dry weight of the material distilled.*

Species.	Locality.	Wood alcohol (100 per cent).			Total acetic acid.		
		Heartwood.	Slabwood.	Mean heartwood and slabwood.	Heartwood.	Slabwood.	Mean heartwood and slabwood.
		Per ct.	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*
Beech	Indiana	1.95	1.79	1.87	5.56	6.18	5.87
Birch	Wisconsin	1.45	1.55	1.50	6.71	6.88	6.80
Maple	do	1.94	1.91	1.93	5.42	5.11	5.26
White elm	Pennsylvania	2.12	1.68	1.90	6.39	[1] 6.61	6.50
Slippery elm	Wisconsin	2.03	1.79	1.91	5.77	5.53	5.65
Silver maple	do	1.89	1.77	1.83	6.30	5.31	5.81
Green, blue, and yellow ash.	Tennessee and Missouri.	1.91	1.43	1.67	4.64	4.14	4.39
Black ash	Wisconsin	1.79	2.04	1.91	5.65	5.16	5.40
Green ash	Missouri	.....	.....	[2] 2.02	.....	.....	[2] 4.51
Chestnut oak [3]	Tennessee	1.22	1.30	1.27	4.88	4.91	4.90
Tanbark oak	California	1.72	.....	.....	6.89	.....	.....
Black oak	do	.....	1.53	[2] 1.66	.....	6.01	[2] 6.76
Swamp oak	Louisiana	1.50	1.31	1.40	4.90	5.43	5.16
Eucalyptus	California	1.33	1.68	1.50	4.58	5.31	4.94

[1] One-third of this sample was slab free from bark.
[2] Limbs.
[3] In case of chestnut oak the mean is not the average, since the slab represented more runs than heart.

VARIATION DUE TO FORM OF MATERIAL.

The elms, silver maple, green ash, blue ash, yellow ash, and swamp oak gave larger yields of alcohol from heartwood than from slabs, but black ash, chestnut oak, and eucalyptus gave the larger returns from the slabwood. Chestnut oak, white elm, and eucalyptus slabwood yielded more acetic acid than the heartwood of these species, following the tendency previously noted in several other species for sapwood to give more acid than heartwood. California black oak limbs (practically all sapwood) gave a large yield of acid.[1] Silver maple yielded more acid from heartwood than from sapwood.

YIELDS PER CORD, ALCOHOL AND ACETATE.

COMPARISON OF YIELDS.

Table 2 is a conversion to a commercial basis of the results given in Table 1. The raw material is expressed in terms of cords [2] and the products are given in terms of gallons of 82 per cent wood alcohol and pounds of 80 per cent acetate of lime. The three standard species are again given for comparison.

The relative yields from the species tested are quite different when compared on the cord basis and on the percentage weight basis. These differences are, of course, due to the large variation in weight per unit volume of the different woods. The two species of elm and the silver maple are much lighter woods than beech or hard maple, and therefore do not compare so favorably on the cord basis. The oaks and eucalyptus are appreciably heavier than the standard species, and consequently have a high relative value per cord.

[1] Compare tupelo gum, Bulletin 129.
[2] The weights per cord are calculated by multiplying by 90 the known weight per cubic foot of air-seasoned material of the species.

TABLE 2.—*Yields of commercial alcohol and acetate per cord of wood.*

Species.	Locality.	Yield of wood alcohol (82 per cent).			Yield of acetate of lime (80 per cent.			
		Heart-wood.	Slab-wood.	Mean heart and slab.	Heart-wood.	Slab-wood.	Mean heart and slab.	Weight per cord, 15 per cent moisture.
		Gallons.	*Gallons.*	*Gallons.*	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*
Beech	Indiana	11.8	10.9	11.4	301	335	318	3,785
Birch	Wisconsin	8.3	8.9	8.6	346	355	351	3.600
Hard maple	do	11.8	11.6	11.7	301	284	293	3,875
White elm	Pennsylvania	10.2	8.3	9.3	280	290	285	3,060
Slippery elm	Wisconsin	10.7	9.5	10.1	276	263	270	3,330
Silver maple	do	8.5	8.2	8.4	260	219	240	2,880
Green, blue, and yellow ash.	Tennessee and Missouri.	12.1	9.1	10.6	262	235	249	3,960
Black ash	Wisconsin	10.1	11.5	10.8	284	260	272	3,510
Green ash	Missouri	.....	[1] 12.8	.....	([1])	257	.....	3,960
Chestnut oak[2]	Tennessee	8.1	8.8	8.5	287	291	290	4,140
Tanbark oak	California	11.4	.....	.....	397	.....	.....	4,068
Black oak	do	.....	9.4	[1] 12.4	.....	327	[1] 451	{ 3,800 [1] 4,650
Swamp oak	Louisiana	9.5	8.3	8.9	278	309	294	3,960
Eucalyptus	California	10.5	13.2	11.9	325	377	351	4,950

[1] Limbs.
[2] In case of chestnut oak the mean is not the average, since the slab represented more runs than heart.

In yields of alcohol per cord, the different species of ash, tanbark oak, and eucalyptus are practically as good as beech and maple. Chestnut oak, swamp oak, slippery elm, and white elm (heartwood) did not compare so favorably with beech and hard maple, but all of them except chestnut oak gave higher yields than birch.

Tanbark oak, California black oak,[1] and eucalyptus are the only species in this group that gave as high yields of acetate of lime as the standard species, although swamp oak and chestnut oak gave practically as good yields as hard maple. Tanbark oak gave a higher yield of acetate than any other species so far tested. The remarkable yield of acetate from California black-oak limb wood is due in part to the very heavy wood. It must be remembered, however, that commercially a cord of limbs would contain much less solid wood than a cord of body wood and the yield would be reduced proportionately.

TABLE 3.—*Relative yields of commercial alcohol and acetate per cord.*

[Average yield from heartwood of beech, birch, and hard maple from Indiana and Wisconsin=100 per cent. Acetate=316 pounds; alcohol=10.63 gallons.]

Species.	Locality.	Alcohol.		Acetate.	
		Heart.	Slab.	Heart.	Slab.
White elm	Pennsylvania	96.0	78.1	88.6	91.8
Slippery elm	Wisconsin	100.7	89.3	87.3	83.2
Silver maple	do	80.0	77.2	82.3	69.3
Green, blue, and yellow ash	Tennessee and Missouri	113.7	85.6	82.9	74.4
Black ash	Wisconsin	94.7	108.6	89.9	82.3
Green ash	Missouri	[2] 120.7		[2] 81.3	
Chestnut oak	Tennessee	76.6	82.5	90.8	92.1
Tanbark oak	California	106.7	.....	125.6	.....
Black oak	do	[2] 116.3	88.3	[2] 142.7	103.5
Swamp oak	Louisiana	89.2	78.4	88.0	97.8
Eucalyptus	California	99.0	124.1	102.8	119.3

[1] A more detailed discussion of the commercial possibilities of distilling the California oaks is given in Metallurgical and Chemical Engineering, Vol. XII, p. 623.
[2] Limbs.

The relative value of the species, obtained by taking the average of beech, birch, and maple heartwood as 100 per cent, is given in Table 3, and the same values are shown diagrammatically in figures 1 and 2.

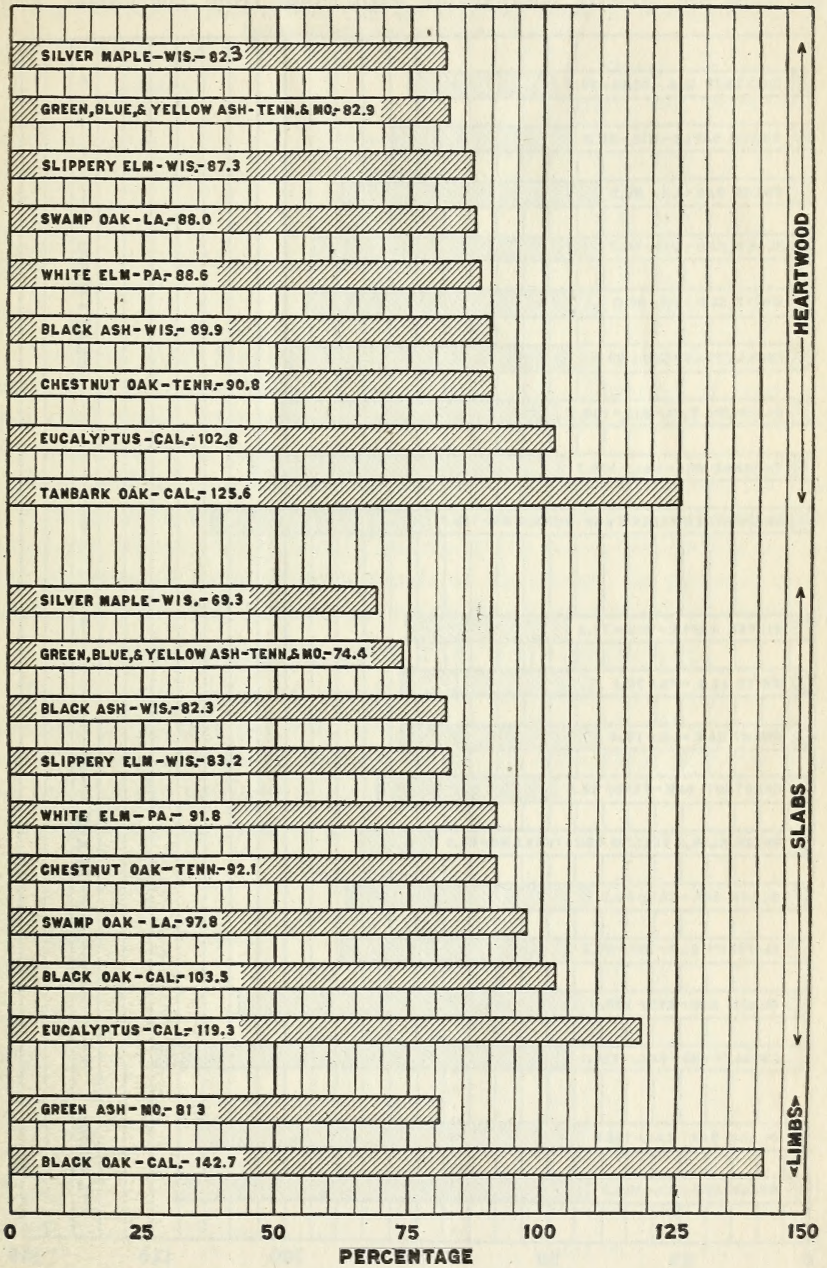

FIG. 1.—Relative yields of acetate of lime per cord. (Average yield from heartwood of beech, birch, and maple from Indiana and Wisconsin equals 100 per cent.)

In Bulletin 129 the averages for beech, birch, and maple included yields from heartwood and lumber. Later experiments on temperature control have shown that in these experiments yields from lumber were not strictly comparable with those from heartwood, and

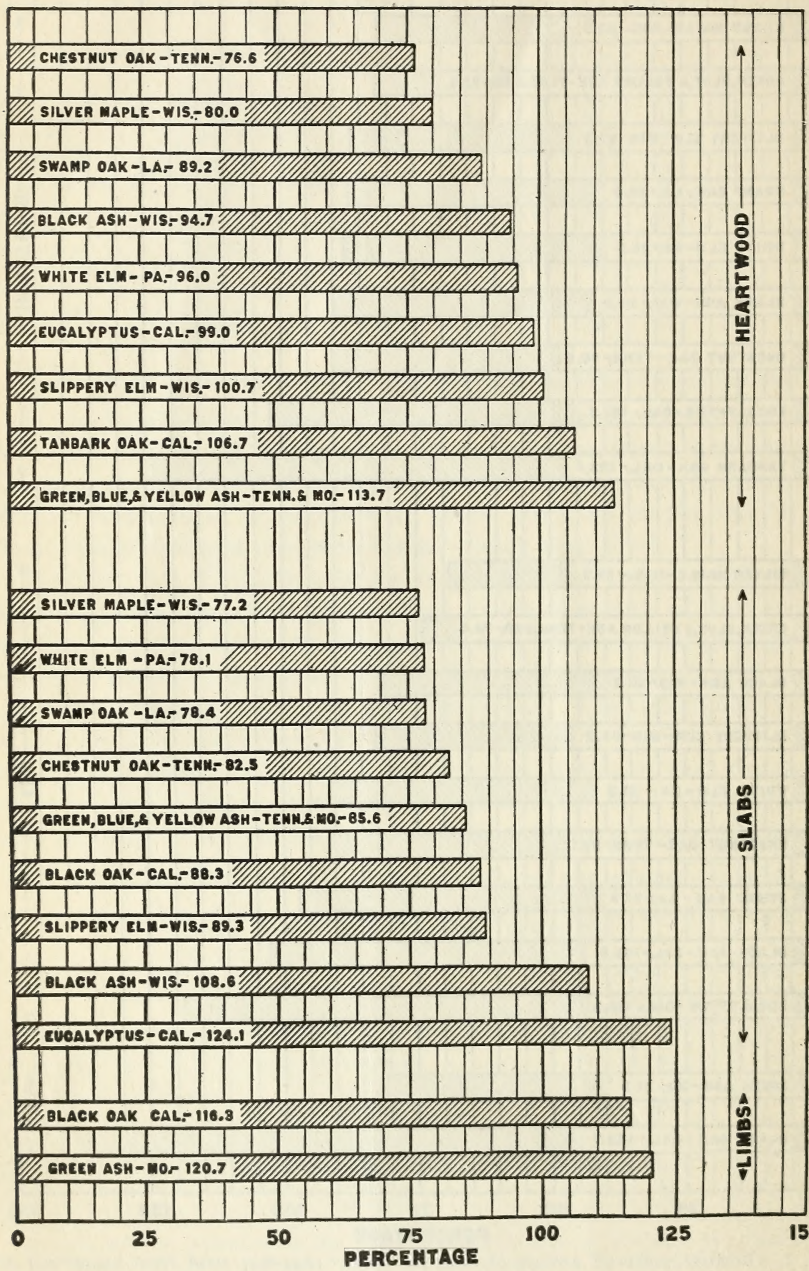

FIG. 2.—Relative yields of wood alcohol per cord. (Average yield from heartwood of beech, birch, and maple from Indiana and Wisconsin equals 100 per cent.)

are therefore omitted in this bulletin. The data from Bulletin 129 corrected to eliminate the yields from lumber are given in Table 4.

TABLE 4.—*Relative yields of commercial alcohol and acetate per cord.*

[Average yield from heartwood of beech, birch, and maple from Indiana and Wisconsin=100 per cent; acetate=316 pounds; alcohol=10.63 gallons.]

Species.	Locality.	Alcohol.		Acetate.	
		Heart.	Slab.	Heart.	Slab.
Beech	Indiana	111.0	102.6	95.3	106.0
Do	Pennsylvania	127.2	118.6	99.1	106.7
Birch	Wisconsin	78.2	83.7	109.5	112.4
Do	Pennsylvania	87.6	85.7	101.0	99.4
Hard maple	Wisconsin	111.0	109.3	95.3	89.9
Do	Pennsylvania	111.6	100.8	99.4	95.4
Red gum	Missouri	88.4	86.7	85.2	78.2
Chestnut	New Jersey	34.8	33.9	62.7	60.2
Hickory	Indiana	144.2			
White oak	do	86.7	86.7	97.7	93.4
Do	Arkansas	86.7	95.2	83.0	85.2
Tupelo	Missouri	82.4	98.0	71.6	82.4

Elm and silver maple, which gave low yields of alcohol and acetic acid, also gave low yields of liquor per cord. The cost of recovery per cord would, of course, be somewhat dependent on the amount of pyroligneous acid to be refined.

The yields of charcoal and tar are only of relative interest. It was not possible in the laboratory tests to determine the value of these products, whose quality is only known in the wood-distillation industry in terms of commercial methods of distilling. In general, however, it is noted that the heavier woods give higher yields of charcoal.

PYROLIGNEOUS ACID, TAR, AND CHARCOAL.

The average yields of pyroligneous acid, tar, and charcoal expressed in pounds per cord are given in Table 5. The yields of pyroligneous acid are of interest mainly in connection with the cost of refining the products from a cord of wood.

TABLE 5.—*Average yields of pyroligneous acid, tar, and charcoal per cord.*

Species.	Locality.	Pyroligneous acid (based on oven-dry wood).			Charcoal.			Tar.			Weight of cord.
		Heart.	Slab.	Mean heart and slab.	Heart.	Slab.	Mean heart and slab.	Heart.	Slab.	Mean heart and slab.	
		Lbs.	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*
Beech	Indiana	1,062	1,165	1,113.5	1,417	1,297	1,357	319	349	334	3,785
Birch	Wisconsin	1,152	1,159	1,155.5	1,315	1,284	1,299.5	325	285	305	3,875
Maple	do	1,120	1,061	1,090.5	1,341	1,515	1,428	418	310	364	3,600
White elm	Pennsylvania	946	997	971.5	1,065	1,055	1,060	322	295	309	3,060
Slippery elm	Wisconsin	984	913	948.5	1,180	1,275	1,228	279	205	242	3,330
Silver maple	do	920	809	864.5	1,030	1,115	1,072	302	201	252	2,880
Green, blue, and yellow ash.	Tennessee and Missouri.	1,162	990	1,076	1,410	1,575	1,492	390	270	330	3,960
Black ash	Wisconsin	1,070	1,040	1,055	1,162	1,234	1,198	348	276	312	3,510
Green ash	Missouri			[1]1,045			[1]1,388		[1]346		3,960
Chestnut oak	Tennessee	1,280	1,072	1,176	1,425	1,685	1,555	368	316	342	4,140
Tanbark oak	California	1,315			1,330			318			4,068
Black oak	do		1,125	[1]1,420		1,389	[1]1,640		333	[1]413	3,800 4,650
Swamp oak	Louisiana	1,089	1,024	1,056.5	1,598	1,630	1,614	251	307	279	3,960
Eucalyptus	California	1,405	1,500	1,452.5	2,065	1,900	1,982	166	377	271	4,950

[1] Limbs.

Where especially high yields of refined products are obtained, there is usually a large volume of crude liquor which must be handled to secure these products. Tanbark oak, California black oak, and eucalyptus all showed high yields of crude liquor per cord and also gave high yields of acetic acid and alcohol, as indicated in Table 2. use of the manufactures from figures 1 and 2. The laboratory yields

COMMERCIAL DISTILLATION.

The results given in this bulletin can be best interpreted for the use of the manufacturer from figures 1 and 2. The laboratory yields of acetate of lime are over 50 per cent higher than those obtained in standard commercial practice, although the alcohol yields do not differ much from commercial yields.

Since the data are compared with the results of laboratory distillations of the standard species—beech, birch, and maple—they are entirely comparable on this basis. In the commercial interpretation of these diagrams, the average yields per cord from Wisconsin and Michigan beech, birch, and maple may be given as 10.5 gallons of 82 per cent crude wood alcohol and 185 pounds of gray acetate of lime. Using these yields as a basis, and taking the relations given in the diagrams, a simple calculation will give an actual cost value for judging the different forms and species for distillation. For example: Taking an average market value for acetate of lime as $1.75 per 100 pounds and 82 per cent alcohol at 26 cents per gallon, the value of these two products[1] from beech, birch, and maple in the commercial plant is, then, $3.24 for acetate plus $2.73 for alcohol, which equals $5.97 per cord. Comparing chestnut oak in figures 1 and 2, the calculation gives $\$3.24 \times 0.915$[2] $+ \$2.73 \times 0.796 = \$5.14$. Chestnut oak is, then, obviously worth about 83 cents less per cord to the distillation plant than the standard species. The slabs alone are worth more than bodywood, a consideration of interest to the sawmill. Tanbark oak indicates a value of $\$3.24 \times 1.256 + \$2.73 \times 1.067 = \$6.98$ for alcohol and acetate, or with equal manufacturing and market conditions, a plant could stand a charge of $4.50 per cord for the raw material.

Of course, many other factors enter into the consideration of the value of any form or species of wood for distillation, but the relative value of the products examined would in each case be the primary consideration.

[1] In this particular calculation it is necessary to assume that the yields of charcoal would not vary greatly. If the calculation with acetate and alcohol indicated the value of the wood to be questionable, the charcoal could not be expected to bring up the result.

[2] Mean of heart and slab.

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